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A novel heterodyne polarimeter for the multiple-parameter measurements of twisted nematic liquid crystal cell using a genetic algorithm approach

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1.Introduction

The optical parameters such as a cell gap, twist angle, and the entrance orientation of molecular direction (i.e. the director angle) are highly important for twisted nematic liquid crystal (TNLC) displays because these parameters are closely related to the optical qualities of the LC display devices. In this article, a new approach for the multiple-parameter measurements of the TNLC cell is developed. Different from the above studies, we propose to use a genetic algorithm for the analysis of the intensity ratio and the phase of detected heterodyne signal from a novel heterodyne polarimeter for measurements through solving inverse problem. Genetic or evolutionary algorithms have been used in recent years as a powerful technique for solving optimization and fitting problems. Their ability to avoid local minima by following many search paths simultaneously makes genetic algorithms a very interesting choice for solving multi-parametric problems. Genetic algorithms do not require a starting point and in general have a greater range of convergence than other inversion techniques. They are readily adaptable to many different problems and also have low computation times. They also do not require the evaluation of derivatives, instead relying on a merit function to improve performance. The experimental results confirm the ability of the proposed heterodyne polarimeter with genetic algorithm to determine the azimuth angle of the entrance LC director α, the twist angle ϕ, and the cell gap d. The proposed study has the advantages of reducing the perturbation of the environment and improving the signal-to-noise ratio (SNR) of the detected signal in the scheme of heterodyne polarimeter.

2.Principles of Operation

Fig. 1 presents a schematic diagram of the measurement system utilized to measure three parameters from a TNLC cell. As shown, the polarization modulator comprises two quarter-wave plates and an EO modulator. The EO modulator placed between two orthogonal quarter-wave plates (QWP) whose slow axes form an angle of ±45 ° with that of the EO modulator. The EO modulator is driven by a saw-tooth waveform signal with angular frequency ω supplied by a function generator. A He-Ne laser was employed as the light source and two Glan-Thompson polarizers served as the polarizer and the analyzer respectively. The TNLC cell is placed between the polarization modulator and the analyzer.

Having passed through the TNLC cell and the analyzer, the electric field in the polarized laser beam can be expressed as

$$\vec{E}=\begin{bmatrix}0 & 0\\ 0 & 1\end{bmatrix}\begin{bmatrix}\cos\alpha & -\sin\alpha\\ \sin\alpha & \cos\alpha\end{bmatrix}\begin{bmatrix}\cos\phi & -\sin\phi\\ \sin\phi & \cos\phi\end{bmatrix}$$

$$\begin{bmatrix}\cos\mathrm{X}-i\cdot\Gamma\cdot\dfrac{\sin\mathrm{X}}{2\mathrm{X}} & \phi\cdot\dfrac{\sin\mathrm{X}}{\mathrm{X}}\\ -\phi\cdot\dfrac{\sin\mathrm{X}}{\mathrm{X}} & \cos\mathrm{X}+i\cdot\Gamma\cdot\dfrac{\sin\mathrm{X}}{2\mathrm{X}}\end{bmatrix}\begin{bmatrix}\cos\alpha & \sin\alpha\\ -\sin\alpha & \cos\alpha\end{bmatrix}\overset{\text{polarization modulator}}{\begin{bmatrix}\cos(\dfrac{\omega t}{2}) & \sin(\dfrac{\omega t}{2})\\ -\sin(\dfrac{\omega t}{2}) & \cos(\dfrac{\omega t}{2})\end{bmatrix}}\begin{bmatrix}1\\ 0\end{bmatrix} \tag{1}$$

with

$$\begin{cases}\mathrm{X}=\sqrt{\phi^2+(\Gamma/2)^2}\\ \Gamma=2\pi d\Delta n/\lambda\end{cases} \tag{2}$$

where α is the azimuth angle of the entrance LC director, ϕ is the twist angle of LC cell, Γ is the linear retardance of the LC cell, d is the cell gap, Δn is the linear birefringence of LC.

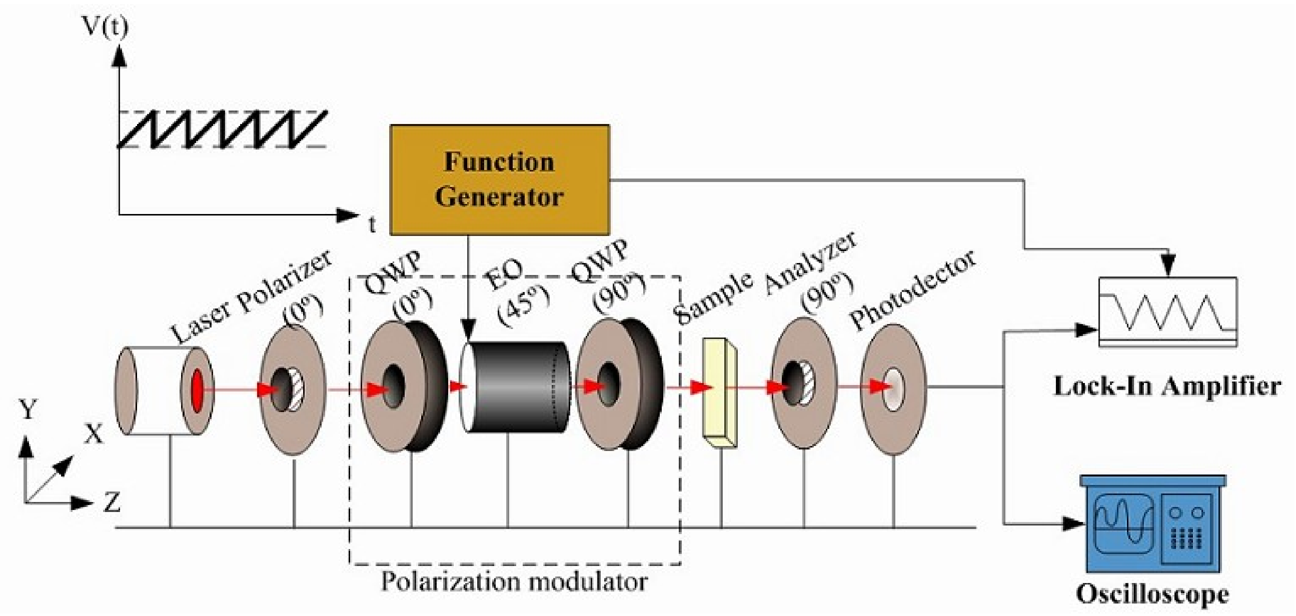


Figure 1 Schematic diagram of TNLC measurement system. QWP: quarter-wave plate; EO: electro-optic modulator; Sample: TNLC cell.

The output signal intensity from the photo-detector can be deliberately simplified as

$$I=I_{DC}+K\sin(\omega t+\sigma) \tag{3}$$

As a result, the detected heterodyne signal would be a sinusoidal signal with the same angular frequency of the driving voltage signal. As can be seen in Eq.(3), the final form of the detected signal consists of a DC term and a modulated term. In the mathematically simplifying process, the DC term, the amplitude and the phase of the sinusoidal term can be expressed as the functions of LC parameters (α,ϕ,d). The phase-lock method can be used to extract the phase $\sigma(\alpha,\phi,d)$ of the detected signal. The intensity ratio, which is defined as $A_G(\alpha,\phi,d) \equiv K/I_{DC}$ in order to eliminate the influence of the perturbation and attenuation of intensity, is also acquired from the oscilloscope.

3.Genetic Algorithm Model for Extracting TNLC Parameters

The genetic algorithm is an iterative procedure that represents the candidate solutions as strings of genes referred to as chromosomes. The viability of these chromosomes is assessed via a fitness function, which represents a measure of the objective to be obtained. Three fundamental operators, namely selection, crossover, and mutation are involved in the genetic algorithm. In the present application, the most suitable TNLC parameters have a greater probability of surviving to the next operator. Within the genetic algorithm, an important process is that of mutation, which causes an existing individual to be modified, and hence introduces an additional variability into the population. This process is important since it can prevent the generation of a local optimal solution. In the mutation process, a species string is picked at random, a mutation point is randomly selected, and the bit information is then changed. The probability in the mutation process is controlled by the mutation probability.

The error function (fitness function) is a measurement of the distance between the computed A_G and σ and the experimental ones. In the current methodology, there are three sets of A_G and σ and each one is associated with three different azimuth angles of the TNLC sample cell. The error function in the present study can be defined as

$$\begin{aligned}\mathrm{Error} &= E_{A_G} + E_{\sigma} \\ &= \left(0.5\times\sum_{n=1}^{3}\left(A_{G_n,\mathrm{Exp}} - A_{G_n,\mathrm{Comp}}\right)^2\right) + \left(0.5\times\sum_{n=1}^{3}\left(\sigma_{n,\mathrm{Exp}} - \sigma_{n,\mathrm{Comp}}\right)^2\right)\end{aligned} \tag{4}$$

where E_{A_G} is the error function of the intensity ratio, E_σ is the error function of the phase term of the detected signal, $A_{G_n,\mathrm{Exp}}$ and $\sigma_{n,\mathrm{Exp}}$ represent the experimental value of intensity ratio and phase respectively in three different azimuth angles of the same TNLC cell. Similarly, $A_{G_n,\mathrm{Comp}}$ and $\sigma_{n,\mathrm{Comp}}$ represent the intensity ratio and the phase computed from the Jones matrix method. The objective of the inverse problem is to inversely derive the parameters (α,ϕ,d) which yield A_G and σ most closely meet the experimental value. Fig.2 presents the major steps of the optimization algorithm.

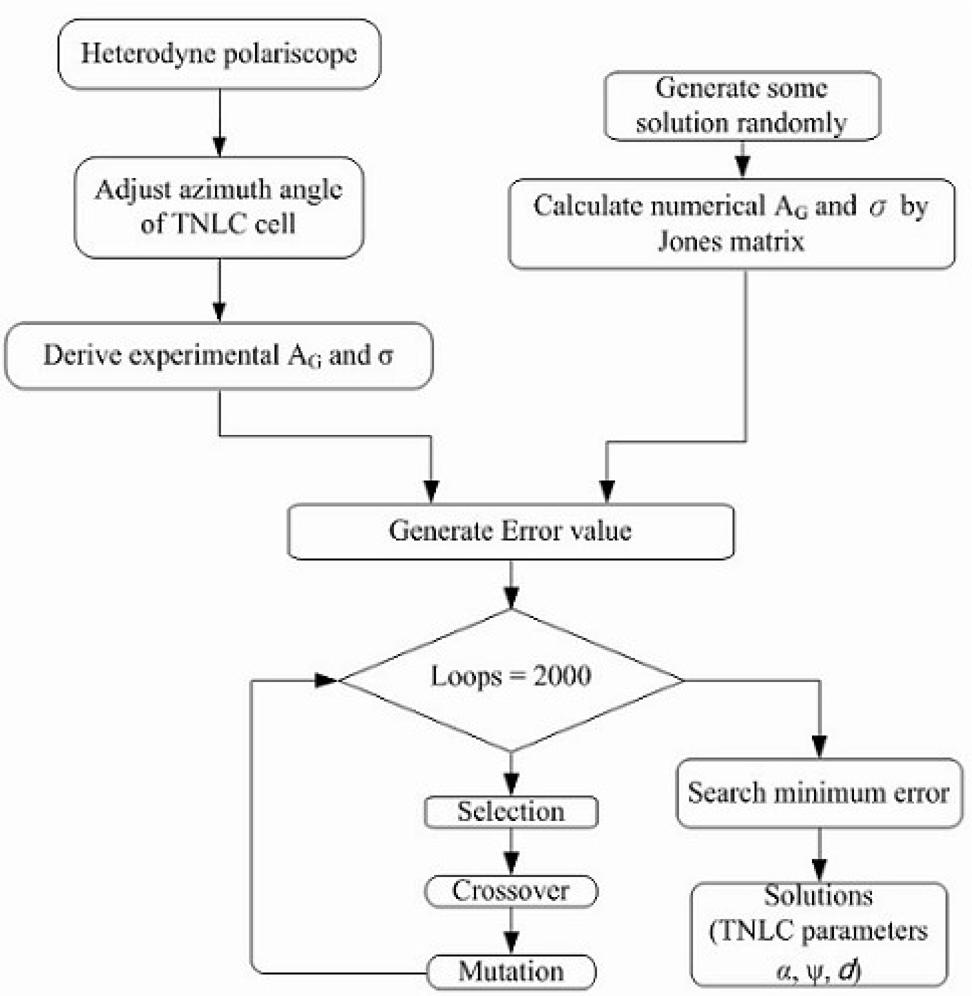


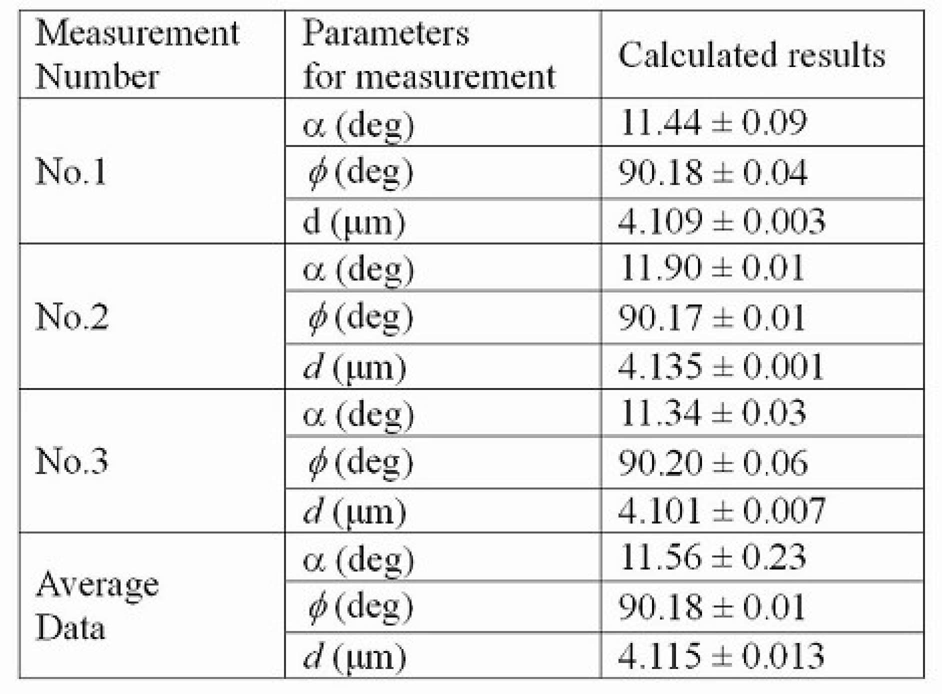
Figure 2 Flow chart of genetic algorithm.

4.Experimental Results

In the schematic diagram of Fig. 1, a TNLC test cell is used as sample in the measurement system. The TNLC cell is with 90 degree twist angle (ϕ), 4.2 micron cell gap (d), 3.4 degree pretilt angle, and the n_e and n_o of the LC are 1.569 and 1.483 respectively. The EO modulator (Conoptics, Model 370) was driven by a saw-tooth signal with 1k Hz frequency. Before the TNLC sample was placed into the experimental setup, the DC bias of EO modulator had to be adjusted to make the detected signal and driving signal in phase (i.e., $\sigma = 0$) for the elimination of the initial phase effect caused by EO modulator.

The experimental results of the TNLC test cell are illustrated in Table I. From Table I, the inversely calculated value of the parameters of the LC sample has good stability in different measurements. The calculated twist angle is about 90.18 degree, which is very close to the data given by manufacturers. However, the cell gap is about 4.12 μm which has a deviation about 0.1 μm compared to the value 4.2 μm provided by manufacturer. The average deviation in twist angle level of 0.01 ° and that in director angle of 0.227 ° are obtained.

Table I Experimental results



Measurement Number	Parameters for measurement	Calculated results
No.1	α (deg)	11.44 ± 0.09
	ϕ (deg)	90.18 ± 0.04
	d (μm)	4.109 ± 0.003
No.2	α (deg)	11.90 ± 0.01
	ϕ (deg)	90.17 ± 0.01
	d (μm)	4.135 ± 0.001
No.3	α (deg)	11.34 ± 0.03
	ϕ (deg)	90.20 ± 0.06
	d (μm)	4.101 ± 0.007
Average Data	α (deg)	11.56 ± 0.23
	ϕ (deg)	90.18 ± 0.01
	d (μm)	4.115 ± 0.013

5.Conclusions

This study proposes an intensity- and phase-sensitive heterodyne polarimeter in which the test TNLC cell is adjusted in three different azimuth angles for the detection of the heterodyne signal. The precision of this proposed method depends on how accurately the phase and the intensity ratio are measured. The system combines the features of optical heterodyne interferometry and genetic algorithm, which makes it possible to present a higher sensitivity of intensity and phase detections and simultaneous multi-parameter extraction in TNLC cells. The detected signal of the modulated light in the system can be simplified as a sinusoidal form (heterodyne signal), which is very suitable for the use of a phase lock-in technique. Furthermore, acquiring the intensity ratio instead of the amplitude can eliminate the intensity variation caused by the absorption of optical elements. In addition, the genetic algorithm is also ideally suited to the multiple-parameter synthesis problem addressed in the study. As a result, the new proposed approach provides a simple configuration and high stability method to measure TNLC parameters.